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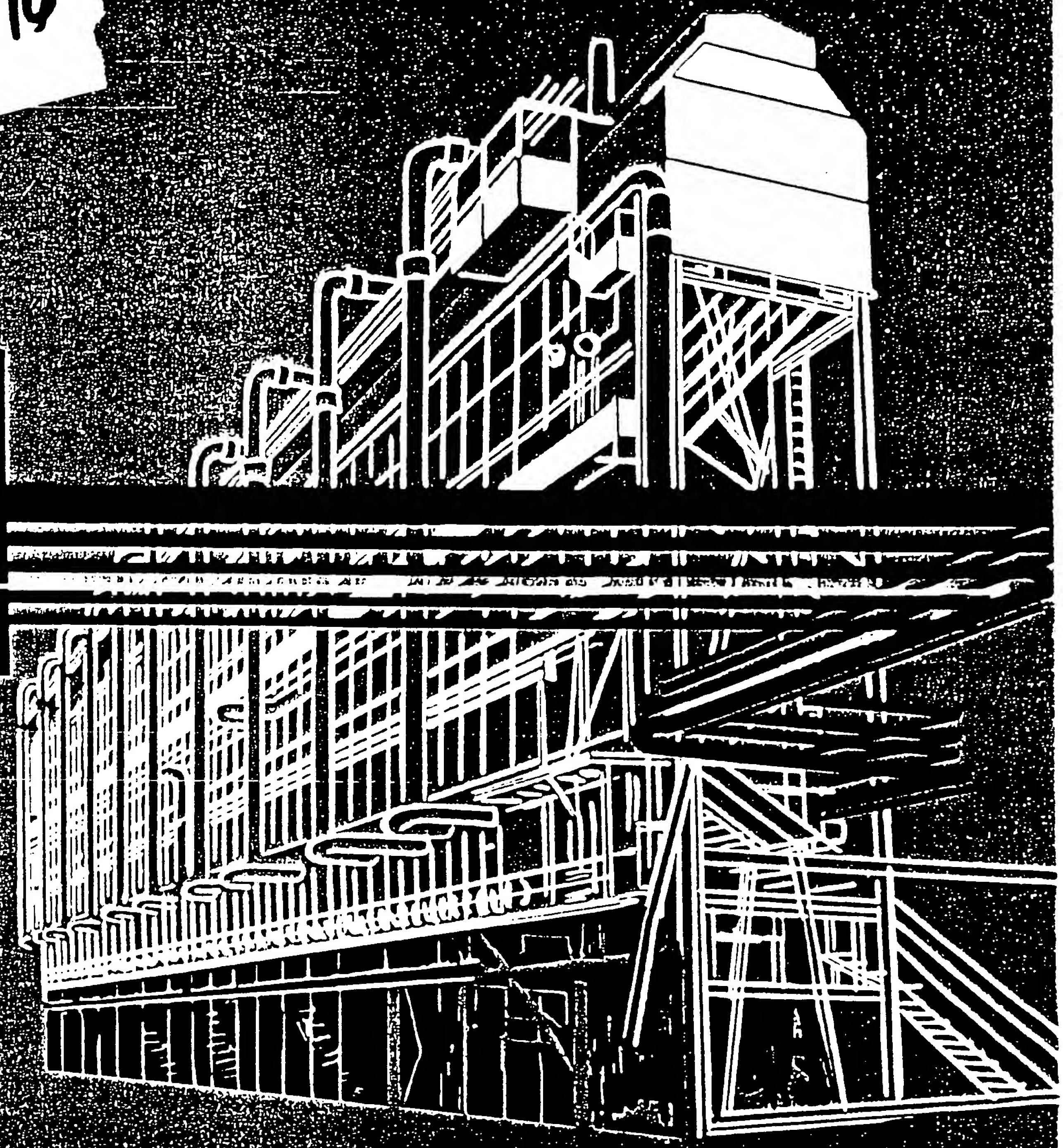
T14

OIL · PROPANE · SULPHUR

KVARN TORP

AMMONIA · BUTANE · GASOLINE · LIME



Svenska Skifferolje AB

Introduction

When the epoch of liquid fuels began with the opening of the first oil wells about 1860, the conditions were created for the enormous technical development which motorization brought about within industry, commerce, agriculture and transportation. Although the world's oil reserves have been adequate so far, the continuing rapid advance in the use of motor vehicles has created an oil demand which the petroleum industry has not always been able to satisfy. This is largely due to the uneven distribution of these reserves over the face of the earth. The struggle of the nations for their vital needs has often been centered around oil. Great resources have been mobilized in order to develop new liquid fuels comparable or superior to petroleum, and the recovery of oil from oil shale figures prominently among the possibilities of utilizing other available sources of supply. Oil shale deposits of varying sizes occur in most countries, bearing potential oil reserves estimated to total about 175 billion tons.

Research on the oil shale problem was commenced in Sweden as early as the 19th century, activities being intensified during the first World War. During the initial phase of Word War II, the Swedish Government, in the emergency which arose, started large-scale recovery of oil from shale in an effort to satisfy the most essential fuel needs of the nation. By mobilizing a large number of technicians and the necessary equipment, a plant was built which furnished the nation with a valuable and indispensable supplement of liquid fuels. When imports of petroleum could be resumed after the war, this plant was expanded and improved in order to make production profitable.

The Swedish oil shale is of low grade and, therefore, a thorough study of production methods designed to attain the highest possible efficiency in oil recovery and the commercial utilization of the valuable by-products were primary conditions for economic operation of this industry. These conditions were the guiding principle in the work of rebuilding the shale oil plant and, at the present time, several high-quality by-products are obtained besides the oil. These include sulphur, lime for agricultural and building purposes, liquefied gases and ammonia. Gas for city requirements and electric power are also produced to some extent. The company's efforts to bring down pro-

duction costs to competitive levels have been successful, and shale oil is now produced on a fully competitive basis.

Through these endeavors a formerly useless mineral is now an important raw material, providing our country with an invaluable fuel and other important products. The Swedish shale oil industry has attracted much attention and aroused considerable interest all over the world. It has been, and still is, the aim of the company to develop a highly efficient industry despite the poor quality of the Swedish shale which, as far as is known, is lower in oil content than that of all other shales currently utilized commercially.

In the hope of furthering a sound development and exploitation of the world's potential natural resources, and especially of stimulating the work of solving the many problems attending the recovery of oil from shale, we present here a brief description of our works.

SVENSKA SKIFFEROLJE AB

Claes Gejrot

Claes Gejrot
Managing Director

History

War Period 1941—45

The history of the Svenska Skifferolje AB, or the Swedish Shale Oil Co as it will be called here, began in 1941 not long after the outbreak of World War II, when Sweden's overseas supply lines were severed. In an effort to ensure the meeting of military, industrial and civilian needs from domestic sources, the Swedish Riksdag and Government initiated several development projects, including the recovery of oil from shale. Following extensive research and surveying work conducted by a team of geologists, chemists and technicians, the Swedish Shale Oil Co was formed early in 1941. The Government invested a total of 50,700,000 Swedish crowns during the initial phase of construction and holds the entire capital stock of the company.

The Swedish Shale Oil Co's plant was built at Kvarntorp in central Sweden where the richest oil shale deposits are located. Work on the project was accelerated because of the extraordinary conditions prevailing during the war, and when the first stage of construction was completed and production got under way in April 1942, the shale oil plant had an annual capacity of 15,000 cubic meters (95,000 bbls.). The production capacity of this plant was expanded in two subsequent stages to a total of 75,000 cubic meters (470,000 bbls.) yearly. Because of the high sulphur content of the shale, the extraction of oil was combined with the production of refined sulphur from the very start. This production largely contributed toward augmenting the short supply of sulphur consumed by the domestic chemical industry. Originally, the production capacity of the sulphur plant was about 5,000 tons annually but was later extended to approximately 22,000 tons.

Period of Reconstruction 1946—53

The second period of the company's history began in 1945. When Sweden again had access to foreign sources of crude and refined oils after the war, it soon became apparent that shale oil could not compete in price with imported fuels without Government subsidization of production. As a result, the company drew up a detailed plan to bring down costs to competitive levels. This plan was based on the experience gained and results achieved in the development work which has been in progress ever since the company was founded. The program, which won approval of the Government, included improvements in the oil production methods and the recovery and utilization of several valuable by-products. The reconstruction work, which required an additional capital investment of 38,000,000 Swedish crowns, was started in 1946 and was completed by 1952. Additional process units have been erected later and now (1958) the company's annual production capacity is:

Crude oil	120,000 cubic meters (750,000 bbls.)
Liquefied gases	12,000 metric tons
Refined sulphur	34,000 ,, ,,
Quicklime	60,000 ,, ,,
Ammonia	22,000 ,, ,,

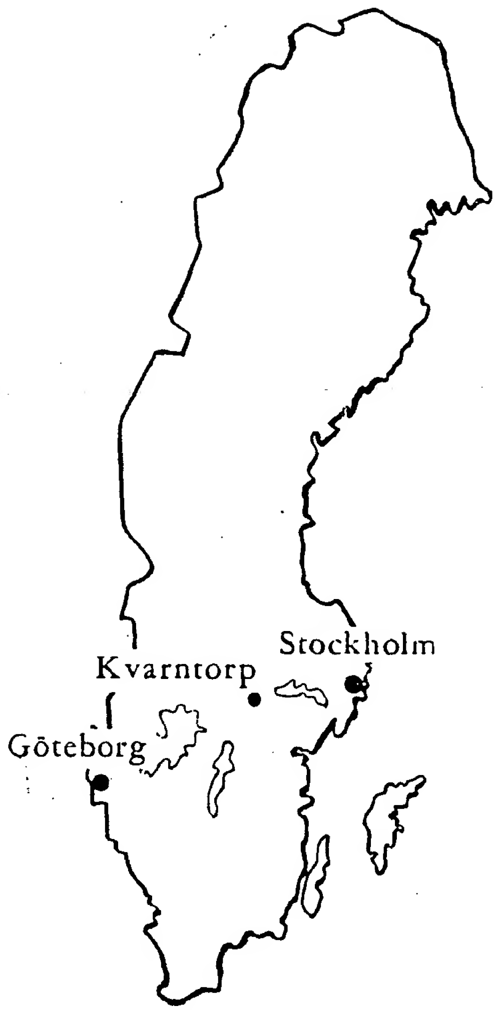


Fig. 1. Kvarntorp is situated in central Sweden.

Table 1.

AVERAGE CHEMICAL COMPOSITION OF KVARNTORP SHALE

	%		%
Silica	44	Hydrogen	~ 2
Alumina	16	Carbon	18
Iron oxide	8	Sulphur	6
Magnesia	~ 1	Moisture	2
Lime	~ 1	Ash	72
Potassium oxide	4	Calorific value	
Sodium oxide	0,5	2,000—2,200 kcal/kg	

Table 2.

FISCHER ASSAY TEST ON KVARNTORP SHALE

Oil	4— 7 % by weight
Gas	40—45 cubic meters per ton
Water	1— 2 % by weight
Coke	85—88 % by weight

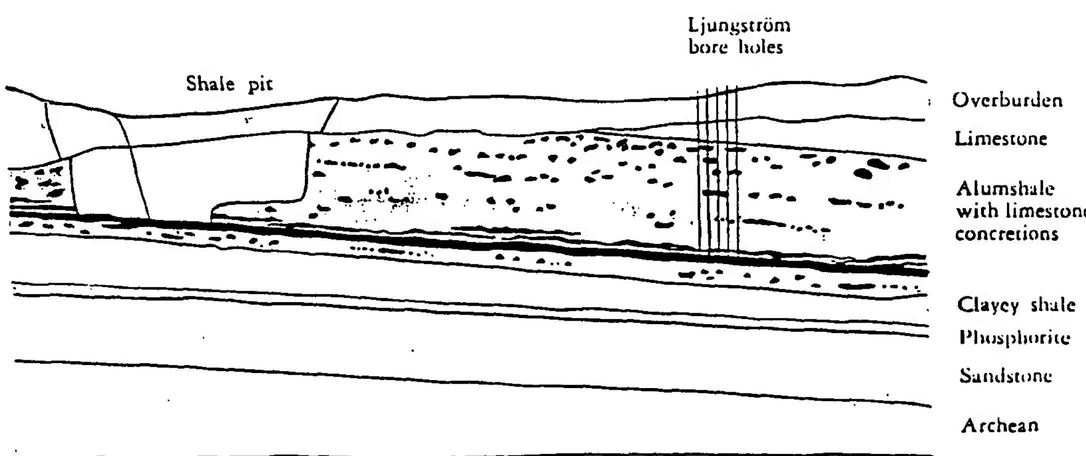


Fig. 2. The shale deposits at Kvarntorp.

Oil Shale

Origin

The principal raw material on which production at Kvarntorp is based is oil shale, a marine sediment which was formed during the Cambrian and Ordovician ages some 400 milion years ago. Vegetable debris was carried by streams from inland areas to shallow sea bays and lagoons, where it was deposited together with dispersed clay and other inorganic matter, dead algae and sea animals. Thus, a mud was formed which is the parent material of oil shale. In time some changes occurred due to the dissolution of some components, precipitation of, for example, calcium carbonate, and to microbic activity etc. During geological intervals the mud formed a hard, compact rock — the shale. Because of varying climatic conditions during its formation, the shale consists of thin layers which, to some degree, differ in composition from one another.

Characteristics

The organic components of the rock are together called *kerogen*. When the shale is heated to a temperature of between 300° and 600° C (570° — 1,100° F), the kerogen changes chemically into *crude oil*, *crude gas* and *carbon*. Together with the inorganic components the carbon forms what is called "spent shale" or "shale coke". The oil and gas are similar to crude petroleum and natural gas but differ from them in some respects. Special techniques must therefore be applied in their treatment and refining into marketable products. The kerogens of different shales give different yields and qualities of oil.

Swedish Oil Shale Deposits

The richest oil shale deposits in Sweden are located at Kvarntorp in the province of Närke (Fig. 1) where oil yields between 4 and 7 per cent by weight are obtained (Tables 1 and 2). The size of these and other Swedish deposits and their locations by provinces are:

Province	Quantity of Shale (Million Tons)	Oil Yield Percentage	Oil Yield Million Tons
Närke	1,700	5	85
Östergötland	5,000	3.8	190
Västergötland	3,000	1.7	51
Öland	3,000	3.8	84
All Sweden	12,700	—	410

Oil Shale Reserves of the World

Oil shale is a common mineral and occurs in many countries. So far, few countries have shown a serious, commercial interest in their shale deposits and, consequently, they have been inadequately surveyed. The world's oil reserves in shale are roughly estimated below.

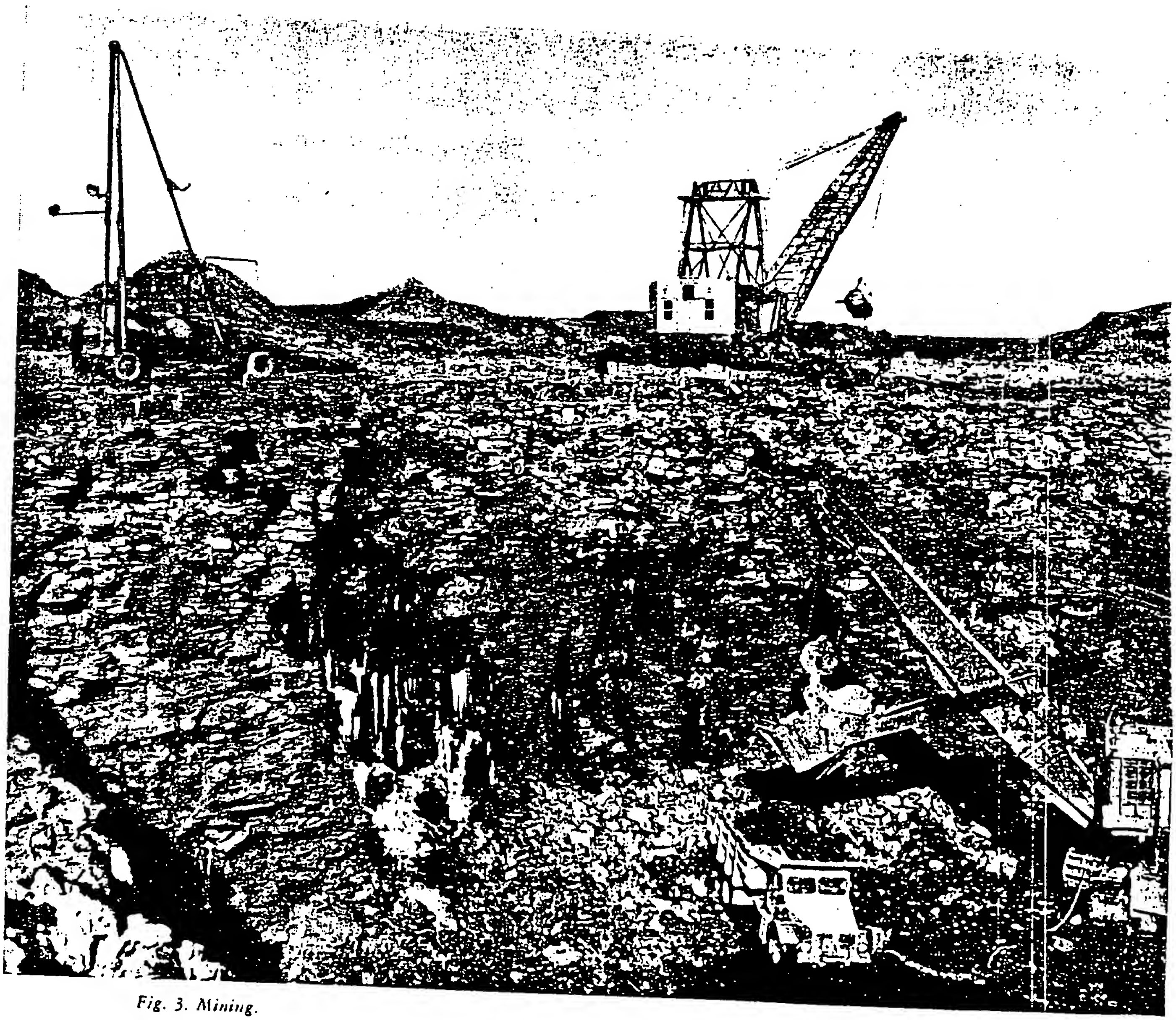


Fig. 3. Mining.

Country	Oil Content in Million Tons
Australia and Tasmania	30
Belgian Congo	15,000
Brazil	50,000
Bulgaria	30
Burma and Thailand	2,500
Canada	5,000
China	400
England	200
Estonia	1,500
France	200
Germany	300
Italy	5,000
Madagascar	30
Manchuria	30
Russia	1,000
Scotland	90
South Africa	5
Spain	40
Sweden	410
United States	90,000
Yugoslavia	200
Total reserves	about 172,000

Mining

As shown in Fig. 2 the shale seam consists of two layers, an upper stratum, giving an oil yield of about 5 per cent, and a lower one, giving a yield of from 6 to 7 per cent. Each of these two layers is between 7 and 8 meters (20 — 24 feet) in thickness. Above the shale is a layer of limestone. The layers tilt slightly toward the south, outcropping in the northern part of the deposit where the quarry is located. Circular, lensshaped limestones are intruded in the shale. Before the shale is mined, the surface soil is removed by a dragline shovel with an action radius of 63 meters (190 feet). The shale is blasted loose with explosive charges, loaded by shovels on trucks and hauled on railway to the crushing plant (Fig. 3).

Crushing and Screening

The first stage of the crushing is performed by two jaw crushers, whereupon the shale is transported on belt conveyors to the separation house where the limestone concretions are picked out by hand (Fig. 4). The coarse shale is crushed further in a Symons' crusher and screened into three different size classes:

Fig. 4. Separation of the limestone.

Fig. 5. Storage silos.

0— 5 millimeters	(0 —3/16″):	the fines (not utilized at present)
5—23 ,,	(3/16″—29/32″):	the screening size, most suitable for Kvarntorp retorts
30—80 ,,	(1 3/16″—3 1/8″):	the screening size for IM and HG retorts

Storage Silos

The different classes of shale are stored separately in eleven concrete silos with an aggregate capacity of 11,000 tons (Fig. 5). From here the shale is carried on belt conveyors to the retorts. The separated limestone is conveyed to the lime kilns.
A total of about 8,500 tons of crushed shale and limestone is produced daily.

Oil Recovery Methods

When the company's production was planned, the aim was to achieve a maximum yield of oil products with a minimum of capital expenditure, material, labour and time. Among the various methods of recovery, existing at the time, the company chose to use the Bergh, IM and HG retorts, as well as the Ljungström *in situ* method.

Thermal and Material Balances

The main advantage gained in combining the aforementioned recovery methods was the favorable heat balance attained in the plant. The Bergh retorts give a certain amount of surplus gas fuel which is profitably utilized by the IM and HG retorts. The latter retorts require more heat but they give, on the other hand, a higher oil yield. Moreover, as the different methods require different screening sizes, and several sizes are always obtained in the crushing of shale, they supplement one another also in this respect.
The Bergh recovery method also gives a certain amount of electrical energy which is used partly to meet the plant's own power requirements, and partly for heating the shale electrically *in situ* (i. e. in its natural or original position) in accordance with the Ljungström method. The latter method is well adapted for working those deposits which are covered with limestone and thus inaccessible with present mining methods.

The Bergh Method

This method of oil recovery was invented by Mr. S. V. Bergh shortly after the first World War. The principal feature of the Bergh retort is that the heat value of the shale coke is utilized for pyrolysis, thus eliminating the need for external sources of heat for this purpose.

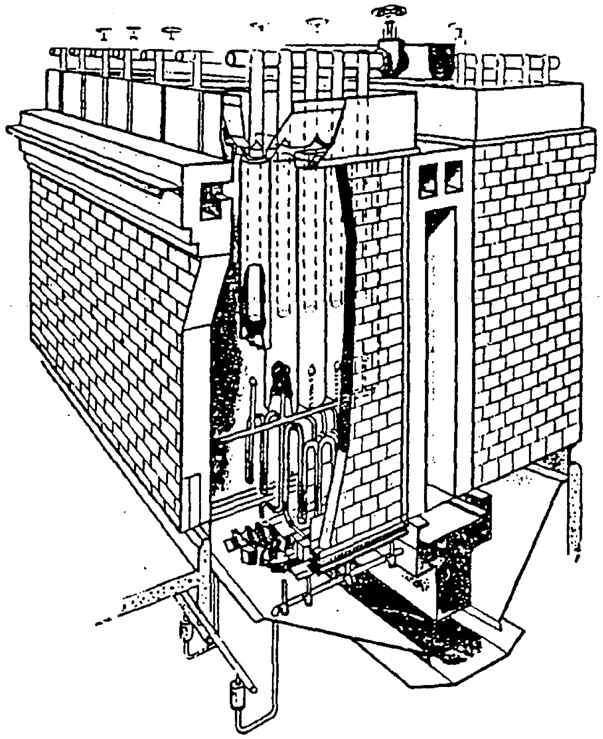


Fig. 6. Block of Kvarntorp retorts.

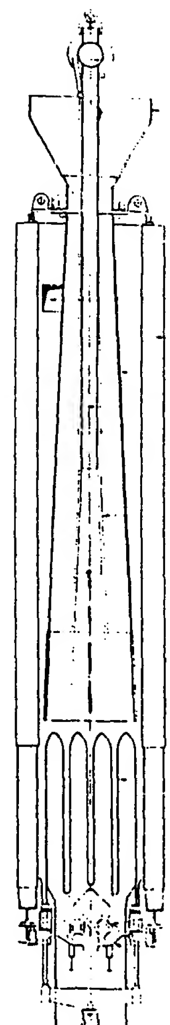


Fig. 7. Section through a Kvarntorp retort.

Fig. 8. The upper part of a Kvarntorp retort house.

Although the Bergh retorts originally installed in the company's plant worked satisfactorily, their production capacity was limited. Experience gained in the company's work, however, led to essential improvements which nearly tripled the production capacity of each retort. All the Bergh retorts at Kvarntorp have therefore been rebuilt in accordance with the modified so-called *Kvarntorp Method*.

The Kvarntorp Retort

The Kvarntorp retort consists of a vertical tube, about 20 cm. (8″) in diameter and 3 meters (9′) in height (Figs. 6—9). Five retorts are arranged together in a brick-walled chamber or *box*. Fourteen boxes form a *block*, and from eight to twelve blocks form a *bench*. The retorts are heated externally by hot flue gases in the chamber. The crushed shale is charged mechanically at the top and passes down through the retort tubes. Preheating takes place in the upper part of the tube, the temperature in the lower end (500°—550° C or 930°—1,020° F) being adequate to pyrolyze the shale. The oil vapors are drawn off through a suction pipe in the center of each retort, extending into the pyrolysis zone.

Coke Combustion

The hot shale coke proceeds through the open lower end of the retort where it is ignited by a preheated current of air. The ascending combustion gases emit their heat on the walls of the retort tube, passing on the way to the chimney a waste heat boiler where more heat is recovered as steam.

In order to prevent the mixing of vapors and combustion gases within the pyrolysis zone, a pressure balance is maintained by means of fans. Moreover, a separation zone is created by charging steam through a pipe ending some inches above the retort's lower end.

As the fusing point of the shale ash is comparatively low (about 950° C or 1,740° F), the temperature in the combustion zone must be carefully controlled in order to avoid caking of the ash. This is done in accordance with the *Kvarntorp Coke Combustion Method* in which the coke bed is cooled by a series of boiler tubes in the shaft. Some of these tubes function as boilers, others as superheaters. Surplus air blown through the roughly 3 feet thick layer of hot ash also has a cooling effect upon it.

Fig. 9. View from the interior of a Kvarntorp retort house.

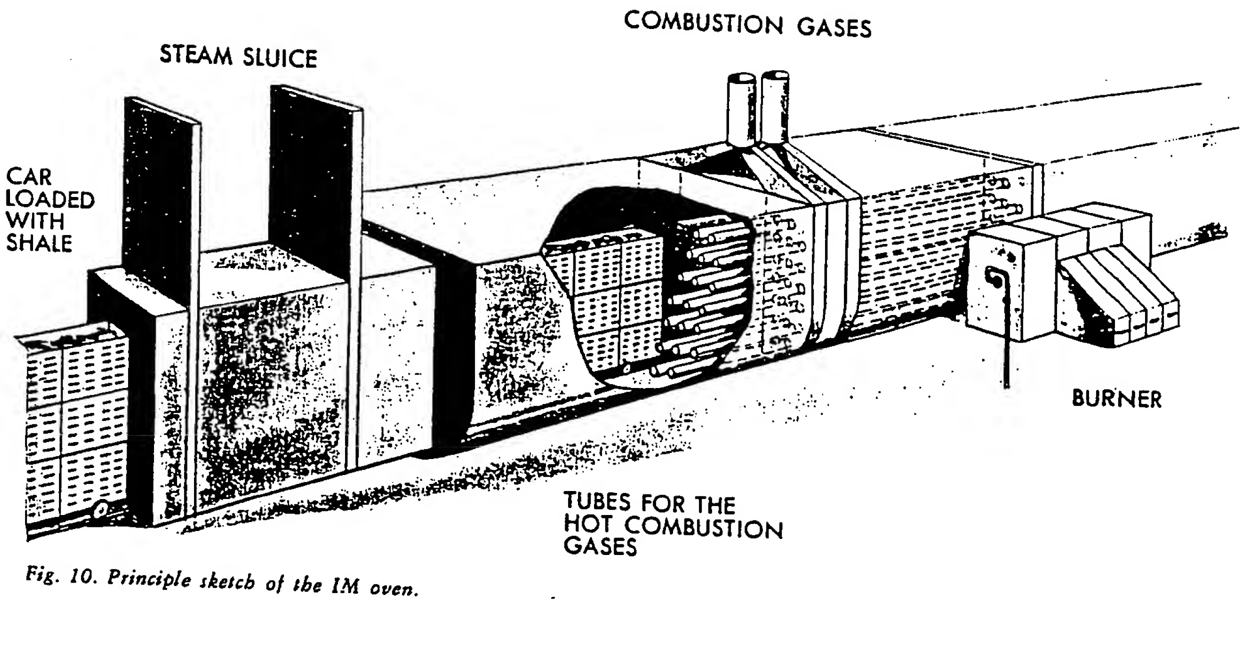


Fig. 10. Principle sketch of the IM oven.

The shale ash is discharged automatically through the bottom of the combustion chamber which is equipped with labyrinths, whereupon it is transported on belt conveyors and dumped on ash piles. The whole process is continuous, each individual retort having a capacity of about one ton of shale a day. At the present time, the company has six benches of Kvarntorp retorts, comprising a total of 3,920 units with an aggregate capacity of 3,500 tons of shale a day. From one ton of Swedish oil shale of average grade the Kvarntorp retort produces:

Crude oil	about 45 liters (12 U.S. gals.)
Crude gas	„ 50 cu.meters (1,770 cu.ft.)
Steam (28 atm, 325°C)	„ 0.9 ton (2,000 lbs.)

The IM Retort

The IM retort was designed by Mr. F. Carlsson (AB Industrimetoder) and was originally used in Estonia with satisfactory results. It consists of a roughly 60 meter (180 ft.) long horizontal, circular tunnel with a diameter of 4 meters (12 ft.). The shale is conveyed through the retort in perforated cast-iron cars, 2.5 m. × 2.5 m. × 0.5 m. (8'×8'×1.5') in size, each capable of carrying about 2.8 tons of shale. The retort accommodates 24 cars at a time. In order to keep out air and to prevent gas leakage during charging and discharging operations, the tunnel ends are equipped with steam locks (Fig. 10).

The heat required for pyrolysis is generated in three oil- or gas-fired burners located beside the tunnel, the hot combustion gases passing through tubes running parallel with it. The heating tubes are arranged in three sections with series of increasing temperatures for the shale to pass (about 350° C, 450° C and 550° C or 660° F, 840° F and 1,020° F). In order to increase the heat transfer, the oil gases formed in the tunnel are circulated through the perforated shale cars by fans in top of the retort. Part of the oil gases are continuously drawn off and condensed in the condensation plant.

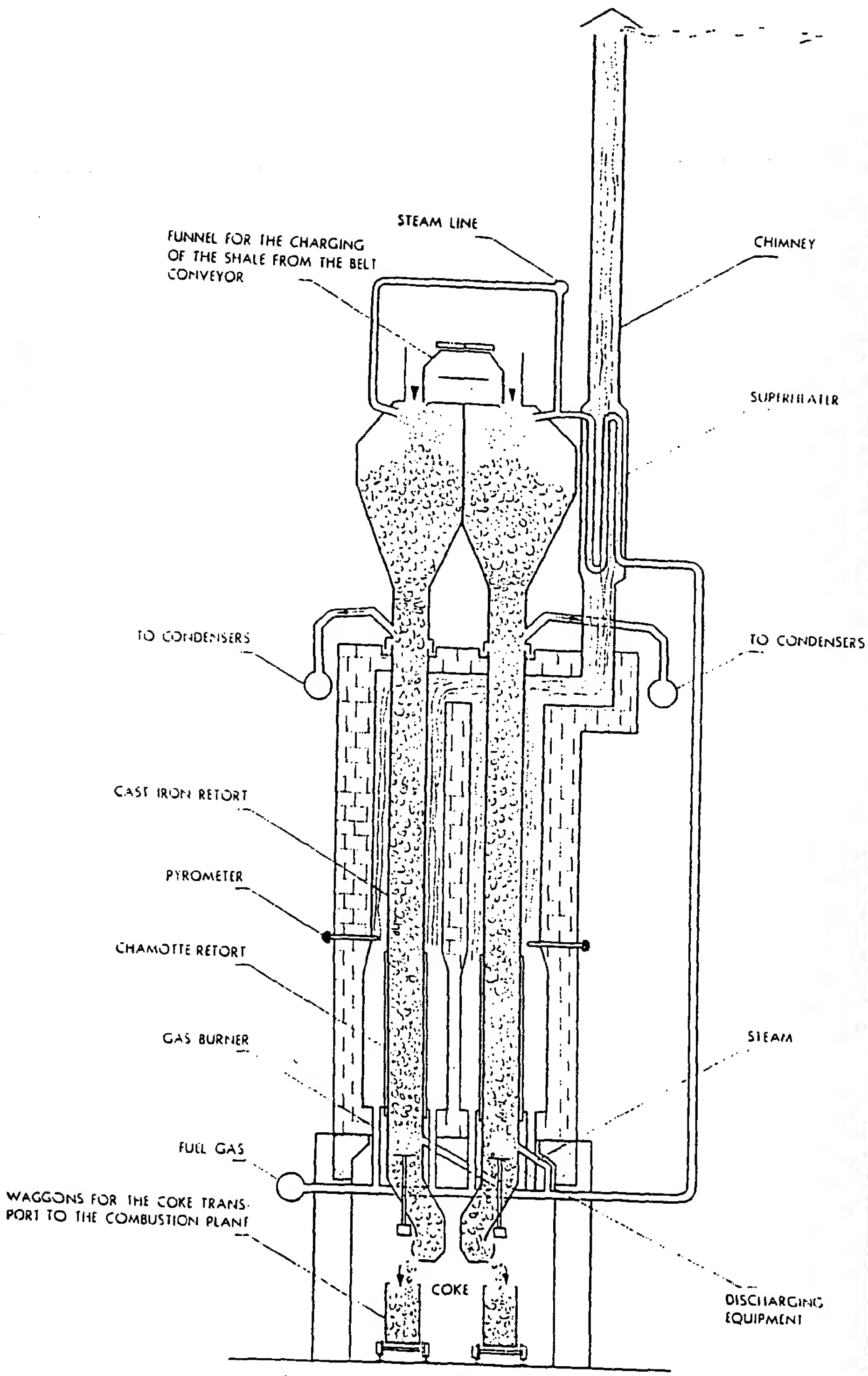


Fig. 11. Section through an HG retort.

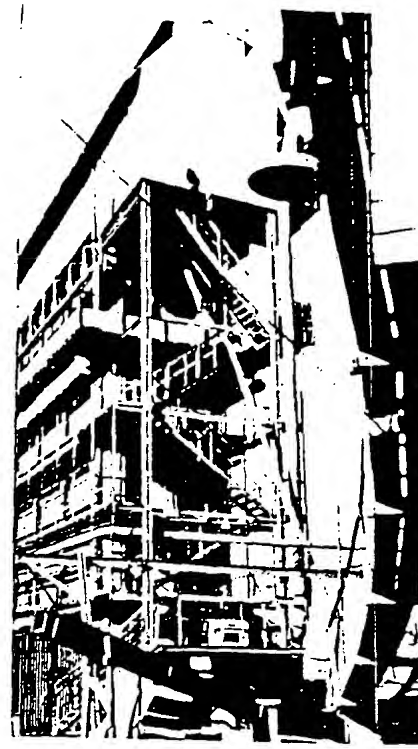


Fig. 12. Exterior of the bench of HG retorts.

Fig. 13. Interior of a condensation plant.

The shale cars are continuously pushed through the retort tunnel. At the exit end the shale coke is discharged through the car bottom and transported to a separate coke combustion plant. There are two IM retorts at the Kvarntorp plant, each with a capacity of 650 tons of oil shale a day.

The HG Retort

The HG (or Rockesholm) retort is a modified Scotch retort designed for Swedish conditions by Messrs. Hultman and Gustafsson. It is a vertical, cylindrical retort, 0.7 meter (2 ft.) in diameter, and 9 meters (27 ft.) in height (Fig. 11). The upper part is of cast iron, and the lower, somewhat wider part, is of refractory brick. The shale is charged through the upper steam trap, moves slowly down the retort and is discharged through the steam trap at the lower end. The retort is heated by a gas burner in a combustion chamber located outside. Superheated steam is admitted at the retort's lower end in order to increase the oil yield and, especially, the gas yield. The temperature maintained in this retort is sufficient to permit some formation of water gas through a partial reaction between the steam and shale coke.

The oil gases are drawn off near the retort's upper end and are condensed in water-cooled tubular condensers. The high temperature maintained during pyrolysis frees some of the nitrogen in the shale in the form of ammonia which is recovered from the condensed pyrolysis water as ammonium sulphate. The discharged shale coke is hauled on cars to the coke combustion plant.

There is one bench of HG retorts at Kvarntorp consisting of 72 individual units with an aggregate capacity of 800 tons of shale a day (Fig. 12).

Condensation

The various retort units are furnished with separate condensation facilities. The cooling and condensation of oil vapors are carried out in tubular cold water coolers (Fig. 13).

The pyrolysis vapors contain some water (moisture and water obtained through chemical reactions during pyrolysis) which is condensed together with the oil and separated from it by settling in cylindrical tanks. The crude oil is pumped to the refinery. The pyrolysis water is de-oiled and purified before going to the drain. The uncondensable gases are despatched to by-product recovery plants.

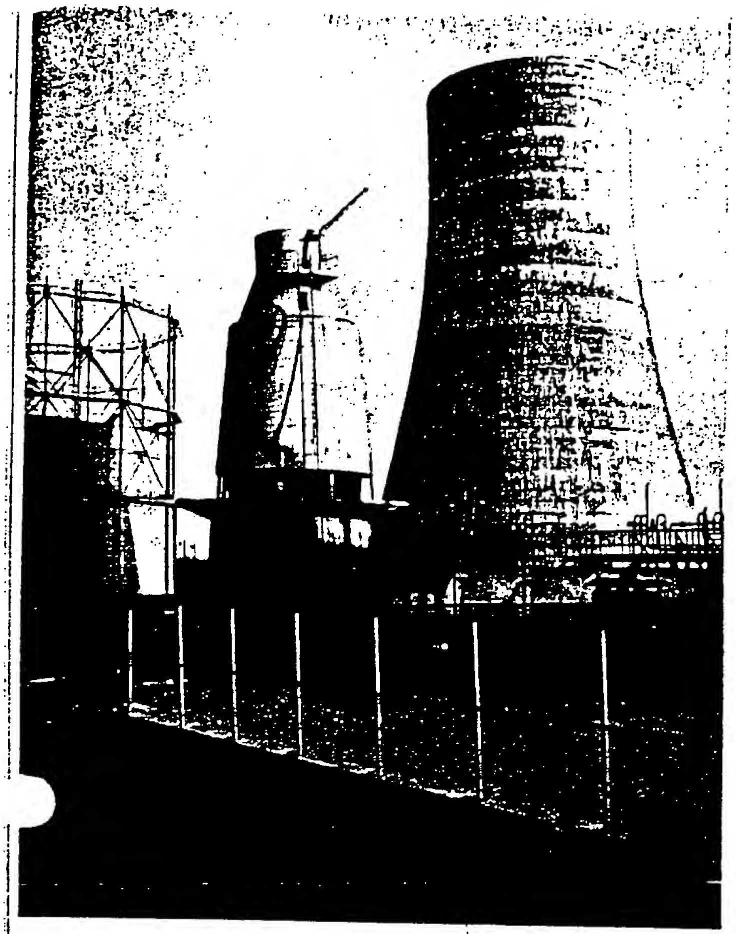


Fig. 14. Cooling tower for water.

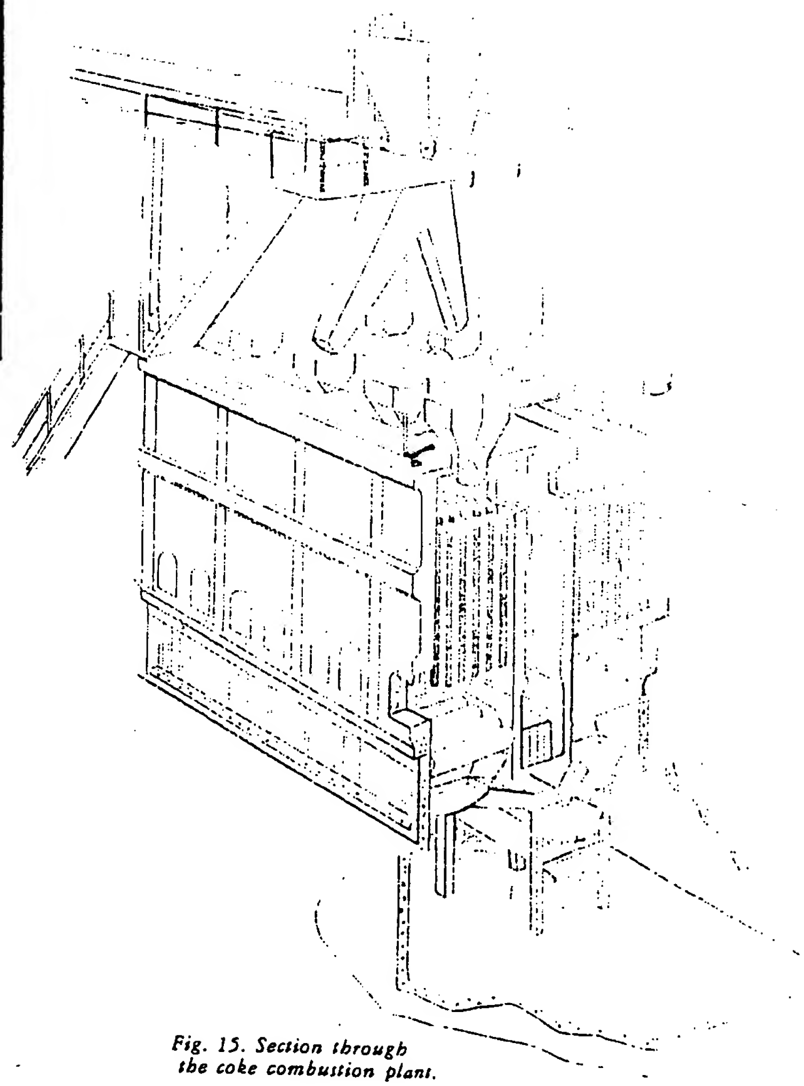


Fig. 15. Section through the coke combustion plant.

The water supply of the Kvarntorp plant is obtained from Lake Tisaren through a 14 kilometer (9 miles) long, wooden pipeline about half a meter (20 in.) in diameter. The bulk of the water used in condensing operations is recooled and recirculated (Fig. 14).

Coke Combustion Plant

As previously mentioned, the shale coke from two of the retort systems (IM and HG) is not directly utilized. This coke has unfavorable pyroforic qualities which preclude its dumping on dump piles. Following the development of the Kvarntorp coke combustion method, it is now utilized for combustion and steam generation, the separate coke combustion unit receiving the coke discharged from the IM and HG retorts. This unit operates on the same principle as that of the Kvarntorp retort, the hot coke being charged into vertical shafts where it is ignited by a hot, ascending current of air. The combustion heat is absorbed by a series of vertical boiler tubes equipped with a water-pump circulation system. These tubes simultaneously cool the combustion zone to a temperature immediately below the melting point of the shale ash. Some of the tubes serve as superheaters. The shale ash moves slowly down the shaft and is discharged automatically on to conveyors. (Fig. 15).

The steam produced is delivered as superheated steam of 30 atm. (430 psig.) pressure to the steam power plant. About 600 tons of superheated steam are produced daily.

Steam Power Plant

The steam generated in the Kvarntorp retorts and in the coke combustion unit is collected in the power plant's steam domes together with the steam from two boilers fired with the surplus pyrolysis gases. Steam is required for several purposes at the Kvarntorp plant, such as for oil refining, sulphur recovery, liquid gas production and ammonia synthesis. The process steam is distributed in a network for high, medium and low pressure steam (23, 10 and 2.5 atm. or 335, 150 and 36 psig.).

The power plant also houses three STAL steam turbines connected to electrical generators with a total generating capacity of 28,000 kilowatts. This plant also serves as a control and switchboard central for the distribution of power to the various units (Fig. 16). The electric energy is distributed as 6,000 V and 380 V power.

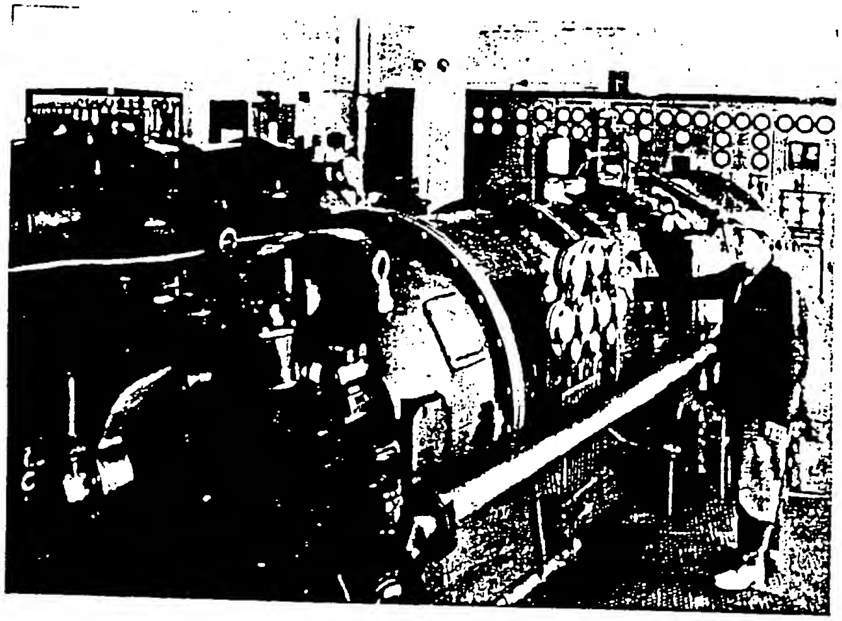


Fig. 16. Steam turbine generators for power production.

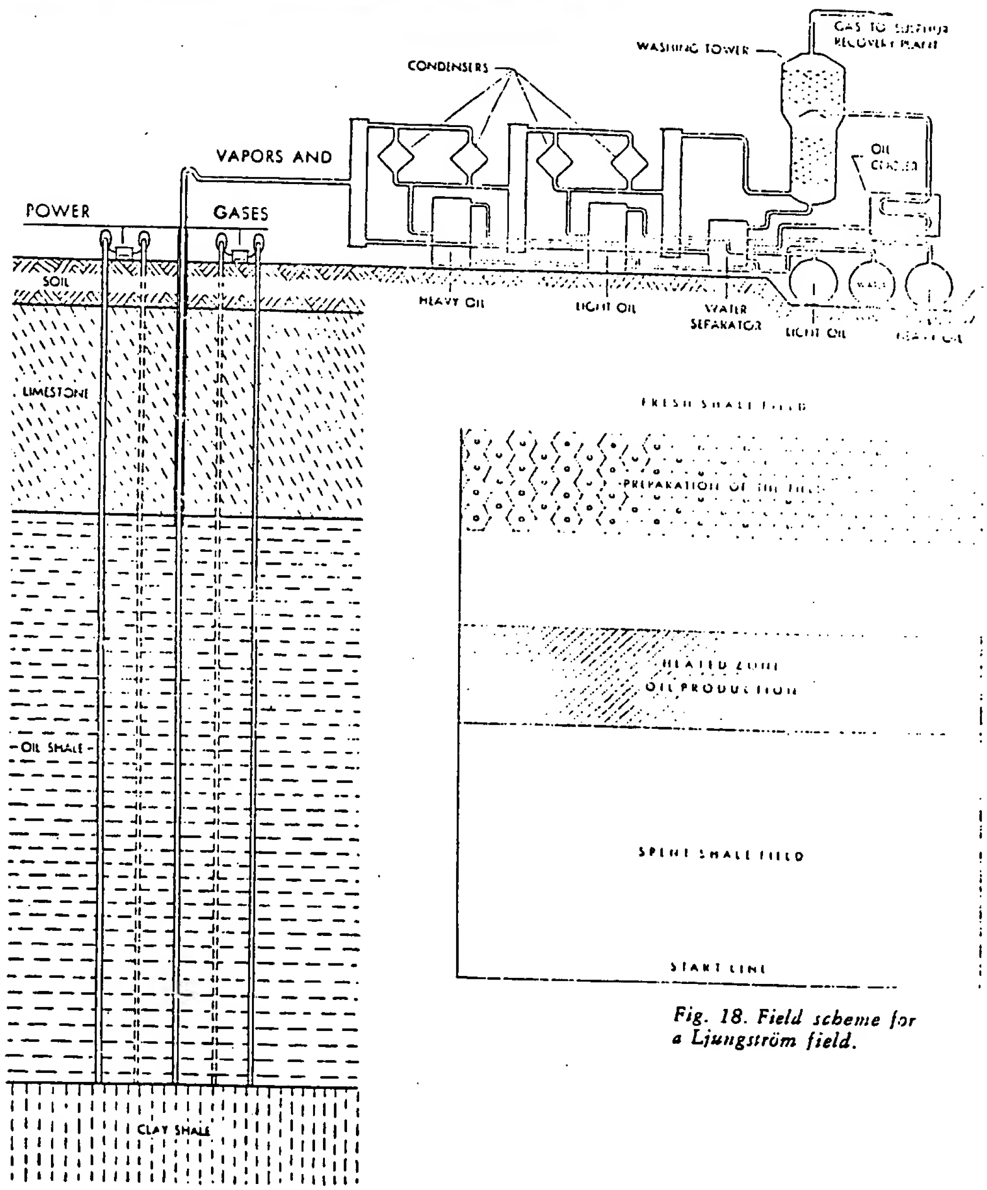


Fig. 17. Process scheme for the Ljungström method.

Fig. 18. Field scheme for a Ljungström field.

The total power consumption is about 13,000 kilowatts in the retort plant, including quarry, retorts, refining and by-product recovery. The Ljungström plant (see below) requires up to 24,000 kilowatts.

The Ljungström Plant

The Ljungström method of oil recovery was invented by *Dr. Fredrik Ljungström* in 1940 and is based on the principle of electrothermal heating of the shale *in situ,* i.e. without first mining it. The oil vapors are collected in a system of production wells.

Field Preparation

The application of the Ljungström method requires a gas-tight cover over the shale, a condition which is present in those parts of the shale deposits at Kvarntorp which are covered with limestone. The field is prepared by draining off the ground water and drilling holes for heating and oil vapor collection. The holes are arranged in a hexagonal pattern with a 2.20 meter (7 ft.) spacing, covering the entire field. The electrical heating elements are placed in the corner holes, the gas holes being located in the centers of the hexagons (Figs. 17 and 18).

The heating elements consist of corrugated ribbons of chrome steel inserted in 2-inch diameter iron tubes and insulated from the tube walls by quartz sand. The oil-gas holes are drilled to the bottom of the shale seam but are lined only through the overburden. The gas holes are connected to a gas-pipe network above ground.

Power Supply

The electric power for *in situ* heating of the shale is supplied by the company's own steam power plant as well as by public power lines. The high-voltage current is transformed in two steps to 152 V, which is the element voltage. The second step is performed by mobile field transformers (Fig. 19). The heat input varies up to 24,000 kilowatts, according to the amounts of power that are available.

Heating

The heating period lasts from four to five months. During the first three months the shale is preheated to a temperature of about 280° C (550° F), the temperature being raised during the remaining months to about 380° C (700° F). During this period and a short time thereafter, the shale produces oil vapors and gases which seep between the laminae of the shale towards the gas holes. A slight superpressure created through the formation of oil and gas is sufficient to lift the vapors through the pipe system, to the condensers, and to the oil tanks and gas holders.

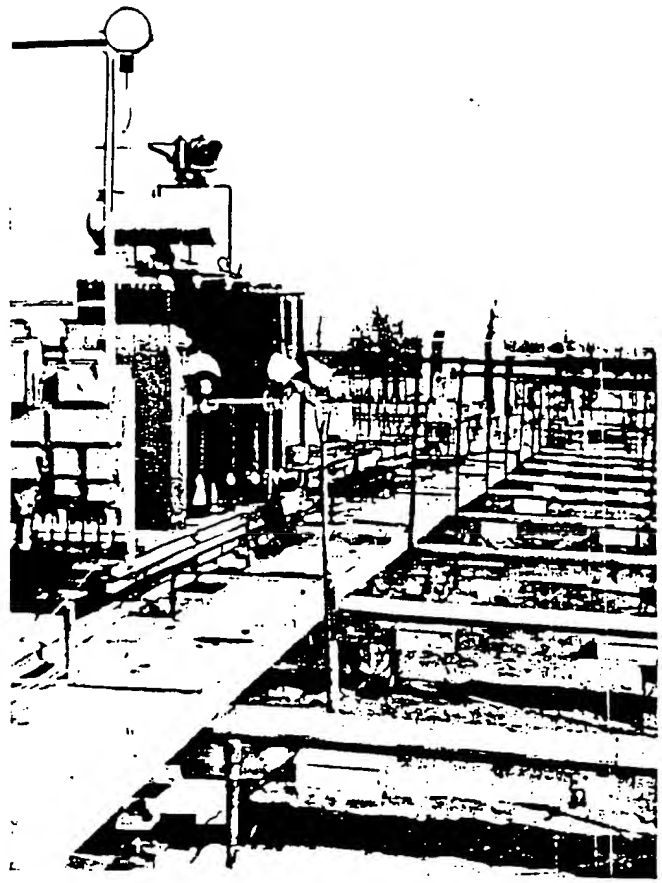


Fig. 19. Mobile field transformer, supply cables and gas-collecting tubes.

Fig. 20. Condensers.

As one part of the field is being prepared, another part is being heated. A tremendous heat wave thus passes through the shale seam at the speed of about 170 meters (520 ft.) a year. The width of the field is 180 meters (550 ft.). A total of about 2,000 heating elements operate at a time.
The oil vapors are condensed in specially designed, air-cooled condensers (Fig. 20). The oil and the uncondensable gases are piped to the refinery and the by-product recovery plants.
The amount of electric power required is in proportion to the quantity of shale heated and not to its oil yield. Hence, the richer the shale, the smaller the power consumption per unit of produced oil. Power consumption also varies according to the size of the field. The larger the field, the smaller the heat and oil losses to the surroundings.

The production per unit of field area averages:

	Per sq. meter	Per sq. foot
Gasoline	370 liters	9.3 gals.
Fuel oil	520 liters	13.2 gals.
Liquid propane and butane	130 kilograms	26.5 lbs.
Gas (8,500 kcal/cu. meter)	730 cu.meters	2,400 cu.ft
Sulphur	280 kilograms	57 lbs.
Ammonia (from the pyrolysis water)	8 kilograms	1.6 lbs.

A field area of 30,000 sq.meters (320,000 sq.ft.), corresponding to about 950,000 tons of shale, is worked each year.

Refining

Topping

The crude oil is steam distilled in a topping still into two fractions, a light fraction boiling between 10° C and 200° C (50° F—390° F), and a heavy fraction boiling above 200° C (390° F).

Chemical Treatment

Because of the high sulphur content of the Swedish shales, the crude oil derived therefrom is also high in sulphur. The light fraction, the *crude gasoline*, contains about 2 per cent sulphur. The sulphur and the discoloring and gum forming substances are removed to meet commercial specifications. This is partly performed by treating the stock with caustic soda and concentrated sulphuric acid in several stages (Fig. 21). Finally, the gasoline is treated with a solution of caustic soda in methanol, which removes traces of carbon disulphide, sweetened with doctor (sodium plumbite) solution, and fractionated (partly under vacuum) into different commercial grades. Two gasoline qualities are produced: regular and premium grades. (Table 3).

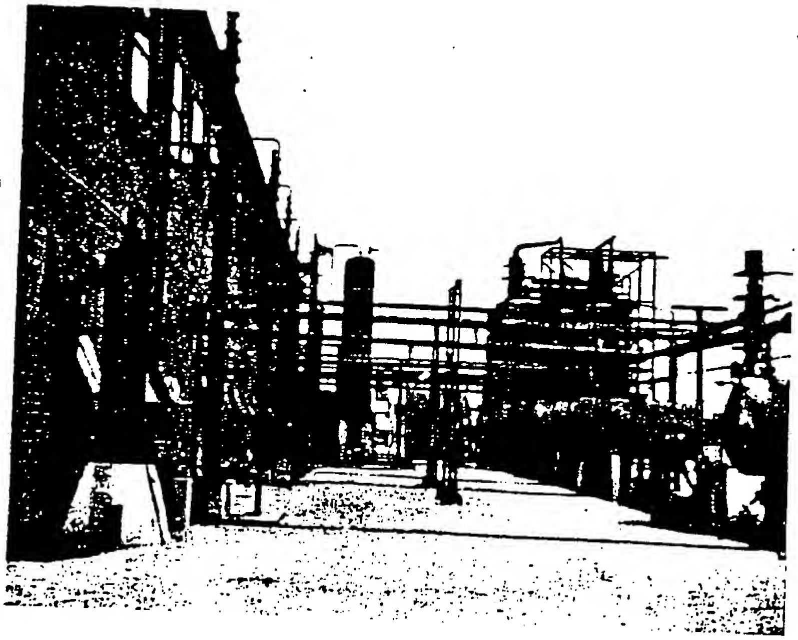


Fig. 21. Part of the refinery.

Table 3.

SPECIFICATIONS FOR GASOLINES

	Regular grade	*Premium grade*
Octane number (Research)	88	93
Corrosion (ASTM)	max. No. 1	
Distillation (ASTM)		
10 % by volume	max. 70°C	
50 % „ „	max. 125°C	
90 % „ „	max. 180°C	
End point	max. 205°C	
Residue	max. 2 %	
Vapor pressure (ASTM)	max. 0.90 kg/cm² at 100°F	
Sulphur	max. 0.20 % by weight	
Doctor test	sweet	
Tetraethyl lead	max. 0.06 % by volume	

Fig. 22. Shipping of oil on railway.

The heavy oil fraction requires no further treatment after topping and is marketed as a medium-grade fuel oil. The topped Ljungström crude oil, on the other hand, is a light fuel oil used for domestic heating purposes. The refined products are stored in a tank farm and are shipped on railway (Fig. 22) and tank trucks. Part of the company's products are marketed under the company's own brand name "Kvarntorp".

Fuel Oil

At the present time, research is concentrated on two important refinery problems, viz. catalytic desulphurization and reforming of gasoline to replace present chemical treatment, and the coking of fuel oil into more valuable products.

New Refining Methods

By-product Recovery from Gas

The Avox Process

The uncondensable gas from the various retorts is collected in a gas holder for further treatment. However, the gas contains some oxygen, and experience has shown that this component causes considerable difficulties in all subsequent processes. Therefore, the oxygen is removed by catalytic combustion with part of the hydrogen present in the gas. This process, which is entirely new and has been developed at Kvarntorp, has been called "The Avox Process". The name "Avox" is an abbreviation of *Active Oxygen Removal.*

Sulphur Recovery

The deoxygenated gas is transferred to the sulphur recovery plant (Fig. 23). This plant consists of four complete units with a total annual capacity of 34,000 tons. The gas is washed with a special liquid that selectively dissolves the hydrogen sulphide, amounting to about 20 per cent (by volume) of the crude gas. The dissolved hydrogen sulphide is drawn off by heating the solution, and through partial combustion and catalytic action the hydrogen is removed as water. The main part of the sulphur production is marketed as a granulated product.

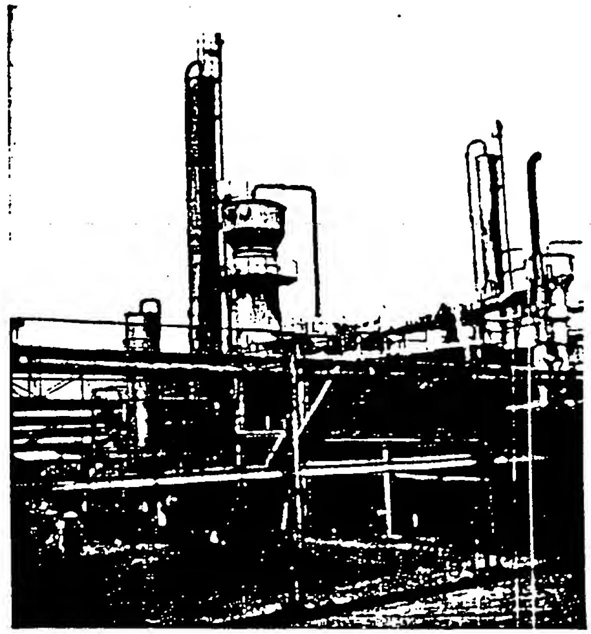


Fig. 23. Part of the sulphur recovery plant.

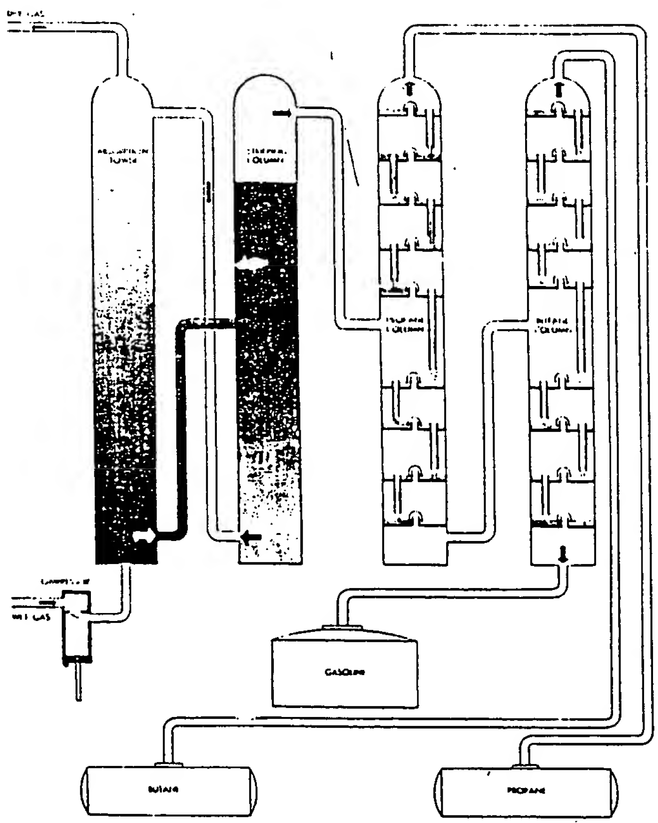


Fig. 24. The basic principles in the LPG recovery.

Fig. 25. The LPG filling station at Kalmar.

Liquid Gas Plant

After treatment in the sulphur plant the gas proceeds to an absorption plant for recovery of propane and butane. Before the absorption, however, the gas is submitted to a final purification by catalytic decomposition of organic sulphur compounds, and extraction of the hydrogen sulphide formed. The absorption is carried out under high-pressure conditions (20 atm., 290 psig.), yielding propane, butane and heavier hydrocarbons (Fig. 24). For domestic and industrial purposes the liquid propane and butane are marketed by the company under the trade name of "gasol". The heavier hydrocarbons form a light gasoline which is refined together with gasoline from the crude oil.
The introduction of "gasol" on the Swedish market has brought to local consumers a new fuel product which had been practically unknown before. The company itself built up the necessary distribution organization with filling stations in various parts of the country (Fig. 25). Bottles were obtained and hundreds of "gasol" service men from the entire country were trained at the company's "gasol" school. "Gasol" is used as a household fuel, industrial fuel, raw material for the production of controlled atmosphere etc. Some cities have already closed down their coal gas works and have changed to distributing diluted "gasol" in their city mains.

Ammonia Plant

During the initial phase of the company's existence, the surplus gas from the retorts was used as fuel for steam power production. For some time the gas was piped to the adjacent city of Örebro, where it was used for household and industrial purposes. As the expansion of oil production capacity increased the amount of surplus gas to more than 10,000 cu.m. (350,000 cu.ft.) per hour, the company investigated the possibilities of profitably utilizing it. A decision was subsequently reached to build an ammonia synthesis plant with an annual production capacity of about 22,000 tons.

Synthesis Gas

For the ammonia synthesis, a pure mixture of hydrogen and nitrogen in the ratio of 3:1 is required. This gas is prepared in a plant operating as shown in Fig. 26. The shale gas hydrocarbons react in a gas cracker with steam, forming hydrogen and carbon monoxide. The necessary nitrogen is present already in the original retort gas mixture. Minor adjustments in the hydrogen-nitrogen ratio are made through addition of air in the cracker. The carbon monoxide is catalytically converted in the presence of steam to carbon dioxide and more hydrogen. The carbon dioxide is removed by washing the gas with water under pressure, whereafter the final purifying takes place in a copper-solution unit. Finally, the synthesis gas is compressed to 300—325 atm. (4,500—5,000 psig.) (Figs. 27 and 28).

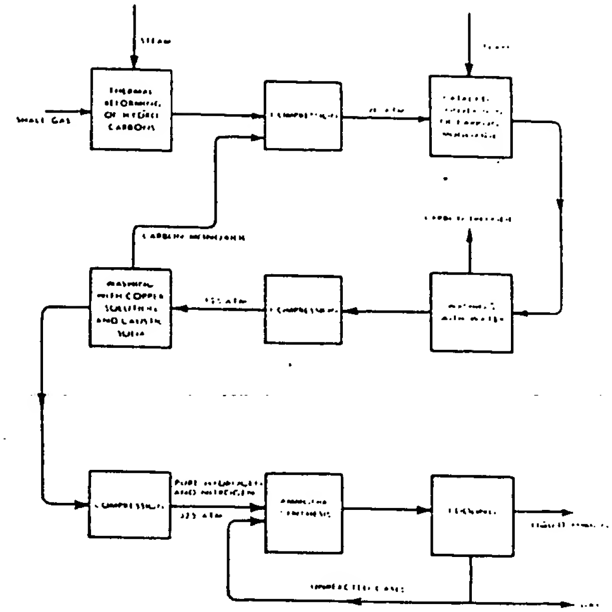


Fig. 26. Scheme for ammonia synthesis.

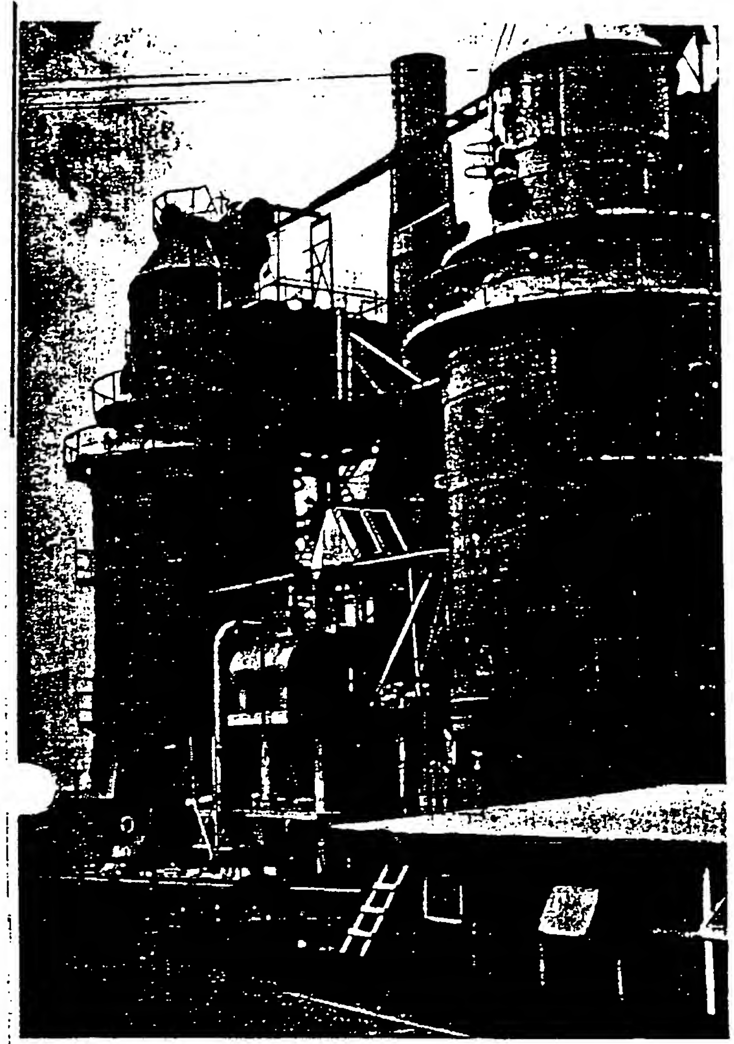


Fig. 27. High temperature equipment for thermal reforming of shale gas.

Fig. 28 Interior of hall for synthesis gas compressors.

Ammonia Synthesis

The compressed gas mixture reacts to ammonia in pressure vessels over a catalyst. The outgoing gas mixture is cooled in a condenser, whereby the ammonia is liquefied and separated. The unreacted gas is recirculated to the reactor.
The produced ammonia is pumped to storage tanks, from which it is loaded on railway tank cars. The whole production is being sold for the manufacture of calcium nitrate and other nitrogen fertilizers.

Lime Kilns

The shale strata contain about 15 per cent bituminous limestone, consisting of ball-shaped stones disseminated in the shale. The limestone is eliminated in order not to encumber the furnace. In order to make use of the limestone, a shaft furnace for lime burning was built in 1946 and two more furnaces the following year (Fig. 29). All three are heated with surplus gas from the works. Their production capacity is 60,000 tons of quick lime per annum. A plant on a smaller scale for the production of a new type of building lime was started in the spring of 1954. Due to a greatly increased demand for this lime, it was soon necessary to step up the production volume. A new factory was therefore built and put into operation at the end of 1956.

Brick Manufacture

The shale ash has good hydraulic properties, making it a suitable base for building materials of various kinds. Research into these entirely new products has been in progress for several years for the purpose of ascertaining the material's aging properties, this being an essential requirement for a good building material. Favorable results have been obtained.

Maintenance and Transport

The maintenance service, employing a total of about 300 men, including engineers and foremen, is divided into the following sections:

- General maintenance section
- Section for maintenance of transport equipment
- Electrical section
- Instrument section

A special operation center has been set up to coordinate the various demands for maintenance. When plant maintenance personnel is inadequate, as may occur with extensive maintenance jobs, outside contractors are called in.

Preventive maintenance

Alongside actual repair work, the plant is continuously checked and overhauled, i.e. preventive maintenance is exercised. This overhaul includes i.a. different machineries and transport devices on rails and off, as well as excavators. The electrical section, for instance, continuously checks about 100 transformers — the largest having a capacity of 25,000 kVA — and the approximately 800 various instru-

Fig. 29. Lime kilns and storage silos.

Fig. 30. Dispensary.

ments of the plant are regularly serviced by the instrument section. Crushers and conveyors are serviced daily and in this way maintenance breakdowns have been reduced to 5—10 per cent. A large part of the lubrication is handled by a special lubrication team and this has resulted in manpower reduction as well as better control and fewer bearing breakdowns.

Corrosion problems

The corrosive atmosphere causes big problems, but thanks to long and extensive experiments it has been possible to attain a comparatively satisfactory paint protection against rust. Corrosion also influences the selection of material, and aluminium is now being used to a great extent, like for instance for exterior roofing, apparatus and circuits. Open air steel structural work is avoided as much as possible and concrete is used instead.

Transport section

A special transport section is responsible for local transports. This section runs some 30 trucks (5—8 tons) and various special vehicles, like excavators, crane trucks, loading machines, bulldozers and graders. In addition there are approximately 10 tank cars (8—16 cu. meters) for distribution of gasoline, fuel oil and "gasol".

Waste Water and Stack Gases

As mentioned earlier, the oily water from the condensation equipment is deoiled before it goes to the drain. Other types of waste water include dilute sulphuric acid from the refinery, spent chemical solutions from the by-product plants, dust-loaded water from air-cleaning scrubbers, sanitary water etc. Because of the importance not to contaminate streams and lakes in the tightly inhabited surroundings, very extensive and elaborate treatment and purification arrangements have been made, including filtration, biological action, oxidation, precipitation and sedimentation.

The stack gases contain appreciable amounts of sulphur dioxide. In order to eliminate corrosion on equipment and damages on growing plants, such as some kinds of forest trees and farm crops, a research program has been started in order to find means of removing the sulphur dioxide from the stack gas. It is foreseen that within few years a process will have been developed which makes this purification economically feasible. In the meantime a careful study of the nature and extent of the damages in the area has been made. Farmers and other parties who suffer from these damages receive annual payment as compensation.

Research

Intensive research is carried on in the laboratories at Kvarntorp. New methods and products have been developed in an effort to attain the most economic utilization of the shale and crude

products derived therefrom. Special problems are encountered in refining operations and in the recovery of by-products due to the somewhat different composition of crude shale oil as compared to petroleum, especially its higher contents of unsaturated and aromatic hydrocarbons and certain sulphur compounds. As previously mentioned, most of the various processes now used at Kvarntorp are based on the results of the company's own research and development activities.

The research division is organized along the following lines:

Control department (analysis methods and routine product control)
Inorganic research department (shale ash, limestone, lime and building materials)
Organic research department (refining and utilization of oil and gas)
Pilot plant department
Pyrolysis research department (new and improved retorting methods)
Library (literature and patents).

Safety and Welfare Departments

Due to the presence of combustible substances in most parts of the Kvarntorp plant, there is a constant fire hazard. Great emphasis, therefore, is laid on fire protection. The plant has its own fire brigade with the most up-to-date equipment.
The potential danger of mechanical and chemical accidents in an operation of this nature makes the work of the safety department very important. All dangerous points of the plant are equipped with safety devices and should an accident occur first aid may be received in a dispensary by the company's doctor (Fig. 30). Modern wash and rest rooms, showers and individual lockers for the workmen's street clothes are available to employees, as well as canteens where hot meals are served.

Adjacent to the works the company has built a little village for its supervisory personnel, maintenance men etc. This village can boast of a community center with school, library, stores, restaurant, assembly rooms, bath and athletic fields, among other things.

The number of employees of the Kvarntorp plant is (1958) about 1,300, including administration and research staffs.

Head office.

The head office of the company is located in the city of Örebro, about 20 kilometers from Kvarntorp. The company's address is: Svenska Skifferolje AB, Västra gatan 2, Örebro, Sweden.

Staff

At present the company's staff includes:

Mr. Claes Gejrot, Managing Director
Mr. Tore Hedbäck, Technical Director
Mr. Rolf Lindskog, Director of Sales
Mr. Edmund Schjånberg, Director of Research
Mr. Åke Tydén, Director of Finance
Mr. Nils Lundin, Superintendent, Maintenance Division
Mr. Gösta Salomonsson, Superintendent, Production Division

Board of Directors

Mr. Harry Älmeby, Stockholm, Chairman of the Board
Mr. Erik Brandt, Stockholm
Mr. Claes Gejrot, Örebro
Mr. Karl Lindström, Stockholm
Mr. Folke Petrén, Västerås
Mr. Claës-Wilhelm Pilo, Stockholm
Mr. Sixten Ulfsparre, Örnsköldsvik

Conclusion

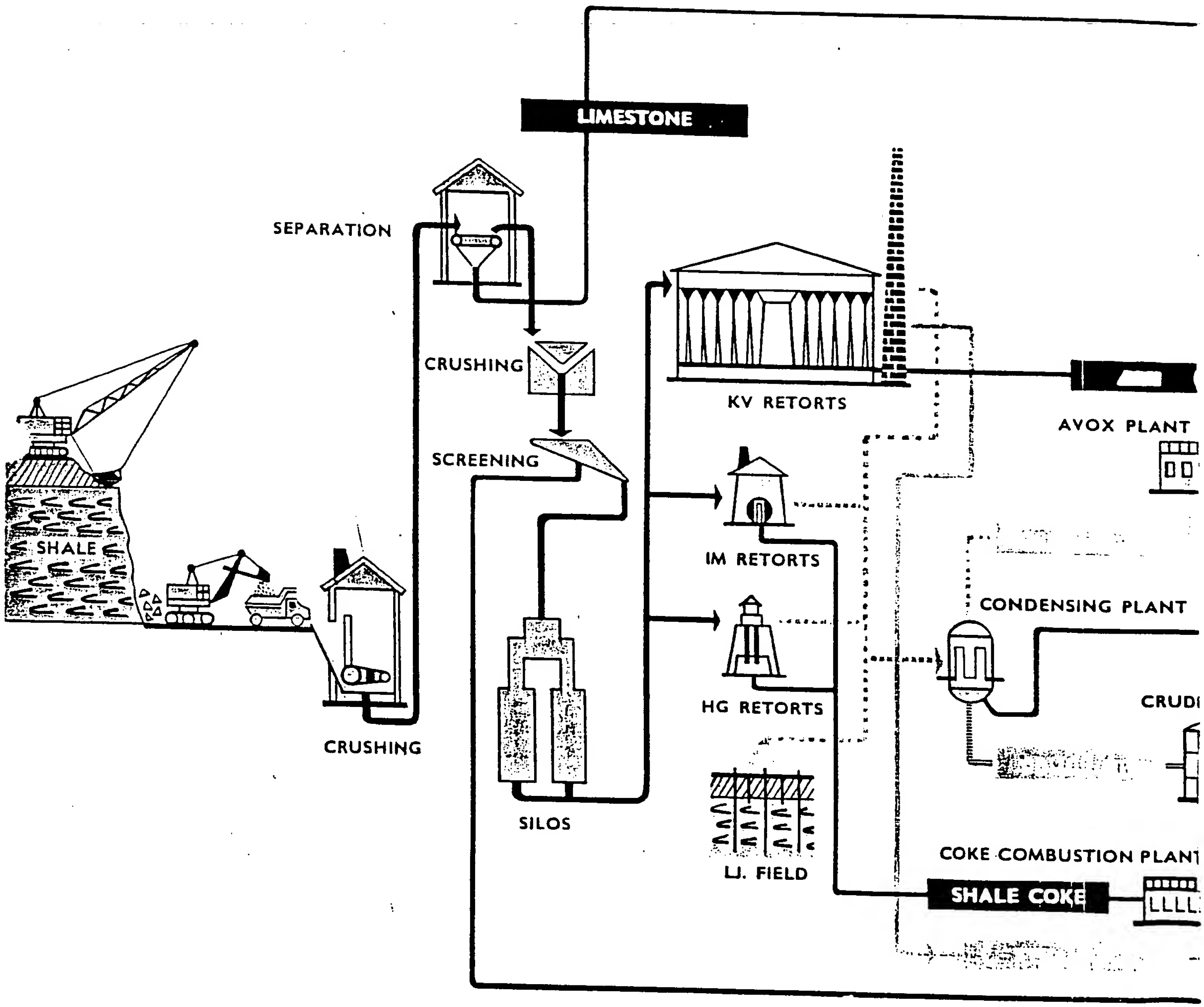
The results achieved at Kvarntorp prove that Swedish enterprise and technique have succeeded in solving the problem of bringing down the cost of producing oil from shale to levels permitting shale oil to compete in price with petroleum. This has been accomplished by combining several processes, that are specially suited to Swedish conditions, through technical improvements and research which have led to the development of two important recovery methods, viz. the Kvarntorp retort and Ljungström methods, and through the large-scale recovery of by-products.

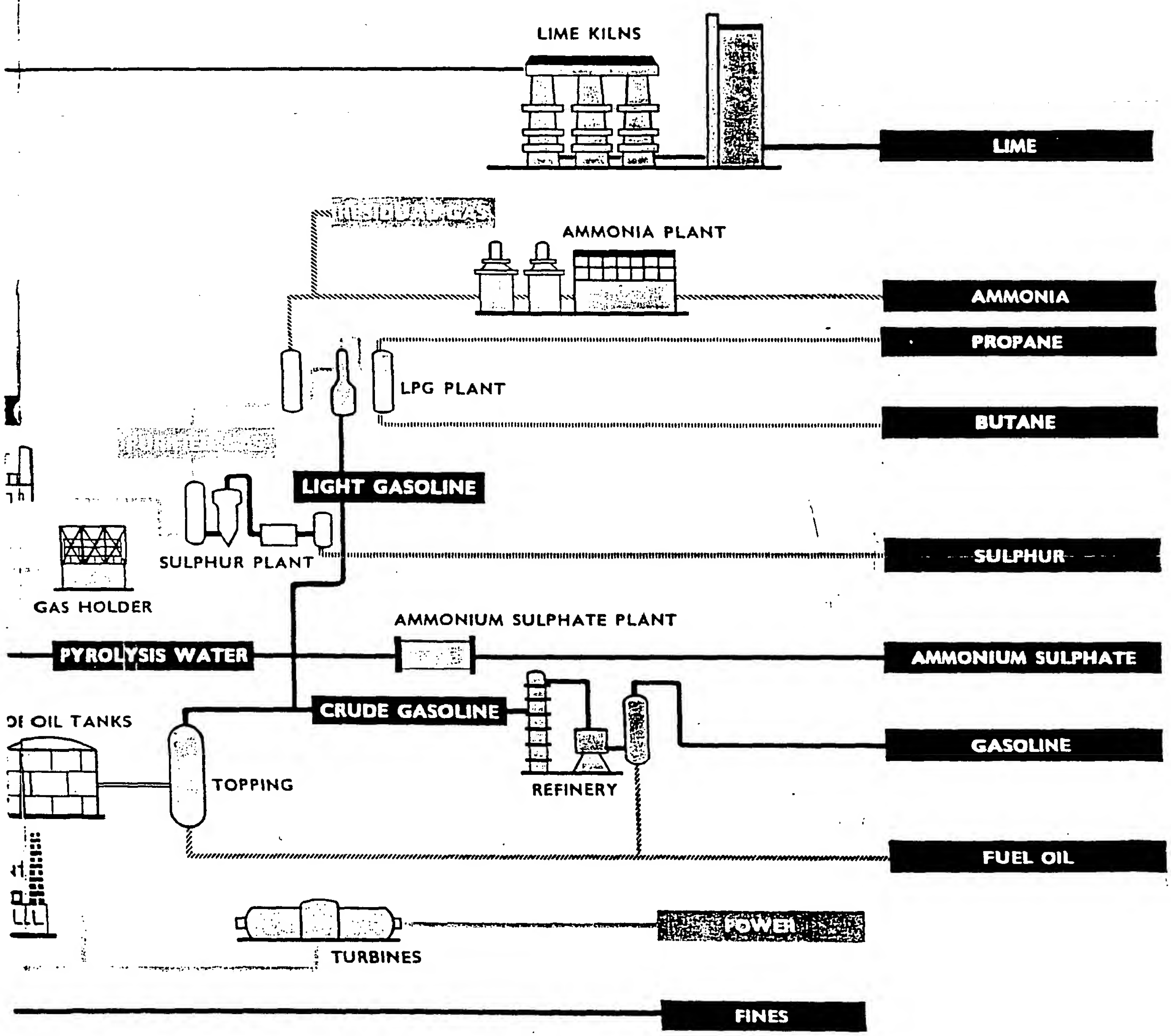
The first steps have thus been taken toward a complete utilization of the reserves of bituminous shale. There is every reason to expect that in the years to come this branch of industrial enterprise will stride further ahead and that realization of the immense potential possibilities of shale will give birth to a world-wide shale oil industry.

PRODUKTION SCHEME

SVENSKA SKIFFEROLJE AB

ÖREBRO SWEDEN




LIME KILNS
LIME
AMMONIA PLANT
AMMONIA
PROPANE
LPG PLANT
BUTANE
LIGHT GASOLINE
SULPHUR PLANT
SULPHUR
GAS HOLDER
AMMONIUM SULPHATE PLANT
PYROLYSIS WATER
AMMONIUM SULPHATE
OIL TANKS
CRUDE GASOLINE
TOPPING
REFINERY
GASOLINE
FUEL OIL
POWER
TURBINES
FINES